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Review

Starch Extraction Methods in Tubers and Roots: A Systematic Review

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Abstract: Starch extraction from tubers and roots has long been an essential process, playing a crucial role in diverse industries ranging from alimentary to pharmacology. This review explores the different methods employed in starch extraction, including traditional techniques and the most innovative mechanical strategies. The methods show a good improvement in many aspects, such as an improvement in the efficiency of the process and an improvement in the yield, showing a value of 10.0–65.0% depending on the starch source. On the other hand, solvents such as NaOH are used in many mechanical processes for alkaline digestion to improve the extraction time. Ethanol and $K_2S_2O_5$ concentrations of 0.5% and 0.8% were used to prevent oxidation and modify some properties of the extracted starch. The use of many solvents has improved the optimization of the processes, providing the final extracted starch with more advantages and better quality. However, using enzymes such as cellulase in new and innovative ways has provided more advantages and a better efficiency and yield than the other methods. Each method has its advantages and challenges, highlighting the importance of understanding the diversity of different approaches and their impact on the yield, sustainability, environmental considerations, and quality of the extracted starch. As the world looks for more ecological approaches, this review shows the importance of critically evaluating the yield, efficiency, and environmental implications of the extraction methods, providing us with more ways of evaluating the methods used for starch extraction. The ecological impact is a crucial point when evaluating the innovation of a new extraction process, which is why methods such as ultrasound and pulsed electric-field-assisted techniques have been proposed. These methods have been presented as sustainable techniques called green technologies, offering more approaches and different advantages than the other methods. This review intends to investigate the complexities and considerations of starch extraction, providing a solid basis for decision-making regarding starch extraction. In a time where sustainability and product quality are crucial elements of industrial strategy formulation, an in-depth understanding of these methods becomes imperative to the development of responsible practices and efficiency in starch extraction.

Keywords: starch; extraction methods; tubers; root

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1. Introduction

Starch is a food with a high energy content. It can provide different nutrients and can make necessary physicochemical changes to our aliments, allowing for variety in the uses of starch, not only in the food industry but also in different industries, such as the pharmaceutical, paper, cosmetic, textile, and polymers industries. Furthermore, it is essential to know about the starch sources presented in this review because there are many

parts of the plants that are not used in actuality and are discarded; for example, the roots and some tubers are discarded. It is crucial to focus on the starch sources because it is necessary to implement a new extraction technique that is capable of taking advantage of these wastes.

All this is in favor of the circular economy and the use of resources. The circular economy is a model of production and consumption, which implies the sharing, renting, reusing, renewing, and recycling of raw materials and existing products at all times, which could be possible via the creation of a plus value. With the support of the circular economy, we can create new approaches in the industry, dedicated to starch extraction, using new and innovative techniques with more efficiency and rentability.

The review also presents different sub-topics, which provide us with many important points for understanding the main issue. Starch extraction is a technique that has been used for many years. The techniques or methods used for starch extraction are varied, comprising traditional, mechanical, and new methods. These include wet pathway, dry pathway, and chemical and enzymatic extraction, as well as the latest techniques such as ultrasound and pulsed electric fields, and further knowledge about all these techniques can be obtained knowledge via comparison of many points, such as the yield, advantages, disadvantages, efficiency, and also the conventional sources of starch used in each method.

This review also covers an essential topic, and this is the environmental impact; this point is one of the most critical in actuality because we are living in a new age, where technology is undergoing constant progress, providing us with more opportunities for the optimization of the methods and techniques used in many industrial processes. The industry of starch extraction needs an evaluation and new, optimized forms of starch extraction should be created, looking toward a future where starch extraction methods become sustainable and have a reduced environmental impact, as well as providing easier opportunities for starch extraction.

2. Common and Unconventional Starch Sources

One of the advantages of the starch extraction industries is the many varied starch sources. Different familiar starch sources have existed for a long time, including corn, potatoes, sweet potato, yucca, yam, and rice (Table 1). These have been used in the industries for starch extraction, causing an increase in the demand for these plants, tubers, and rhizomes. This has provided an excellent opportunity for the optimization of these methods.

Table 1. Main starch sources used in starch extraction.

Type	Technique	Starch Source	References
Traditional	Wet	Taro	[1]
		Low-quality potatoes	[2]
		Chinese yucca	[3]
		Taro (*Colocasia esculenta)*	[4]
		Palmyrah	[5]
		Potato, yucca, and sweet potato	[6]
		Potato (Solanum tuberosum), white lioness variety	[7]
		Canna indica L.	[8]
		Hawthorn yam	[9]
		Yam (*D. cayenensis*, *D. dumentorum*, and *D. bulbifera*) and taro (*X. maffa Scoth*)	[10]
		Indian stick	[11]
		Creole potato	[12]
		Yam	[13]
		Taro (*Colocasia esculenta*)	[14]
		Yucca	[15]
		Ipomoea batatas, Arracacia xanthorriza, Colocasia esculenta, Xanthosoma sagittifolium, and *Dioscorea trifida* (white and purple)	[16]

Table 1. *Cont.*

Type	Technique	Starch Source	References
Mechanical	Dry	Taro (*Colocasia esculenta L. Schott*)	[17]
		Dioscorea trífida	[18]
		Mapuey (*dioscorea trifida*), white and purple variety	[19]
		Colocasia esculenta (L.) Schott and *Xanthosoma sagittifolium* (L.) Schott	[19]
		Canna edulis	[20]
		Dioscoreas	[21]
		Taro (*Colocasia esculenta* L. Schott)	[22]
		Red and white potato varieties	[23]
		Yucca	[24]
		Xanthosoma sagittifolium y *Colocasia esculenta*	[25]
		Pachyrhizus ahipa	[26]
		Taro peel	[2]
		Palmyrah	[3]
		Potato (*Solanum tuberosum*) white lioness variety	[6]
		Yam (*D. cayenensis*, *D. dumentorum*, y *D. bulbifera*) and taro (*X. maffa Scoth*)	[8]
	Crushing and pressing	Creole potato	[10]
		Mapuey (*Dioscorea trifida*)	[19]
		Purple yam (*Dioscorea trifida*)	[27]
		Inhambu	[28]
		Andines grain (amaranth, quinoa y canihua)	[29]
		Taro	[30]
		Dioscorea opposita thunb	[31]
		Yucca	[32]
	Centrifugation	Taro	[33]
		Makal (*Xanthosoma yucatanensis*), sweet potato (*Ipomea batata*), yucca (*Manihot esculenta Crantz*), and sago (*Marantha arundinacea*)	[34]
		Taro	[35]
		Yellow skin potato	[36]
		Chinese yucca	[3]
Chemical & Enzymatics	Use of solvents	Taro (*Colocasia esculenta* L. Schott)	[17]
		Yucca, yam, taro, and others	[37]
		Pachyrhizus ahipa	[26]
		Purple yam (Dioscorea trifida)	[27]
		Achira	[38]
		Taro	[30]
		Taro	[33]
		Chinese yam	[36]
		Wild yam	[39]
		Ariá (*Goeppertia allouia*)	[40]
		Taro (*Colocasia esculenta*)	[41]
		Cyperus alulatus	[42]
	Use of enzymes	Potato	[43]

The research has presented new initiatives that provide new, unconventional starch sources and extraction methods that could reduce the actual demand for the resources used in starch extraction and the food industry. The new proposed starch sources are pulses, pseudocereals, tubers, and roots. To focus on one of these, we have starch extraction from pulses, which is more complex due to their higher protein and lipid content and their smaller starch granules compared with other starch sources. The starch from pseudocereals can be isolated via wet milling. Other recently proposed alternative sources of starch include trees, herbs/shrubs, and fruits; isolating starch from these sources involves wet milling procedures in the presence or absence of chemical solutions [44].

Starch is the major component of pulses, accounting for between 35% and 60% of the total mass, whereas the protein content ranges from 14.9 to 39.4%. Wet and dry milling are the most conventional methods for extracting starch from pulses. The research notes that the dry milling process promotes a greater degree of starch fragmentation and, consequently, a

higher amount of damaged starch, which directly affects the physicochemical properties of starch [45].

Starch from pseudocereals can be isolated by wet milling methods, which involve soaking procedures, wherein the temperature and concentration of the chemicals (alkali or acid) are varied. Some unconventional sources contain significant amounts of starch and may be used as alternatives to traditional ones. Using new sources could provide starches with new advantages and results, including sources of starch with unique functional properties, which could be used to develop several food products [44].

3. Traditional Methods

Diverse starch extraction methods exist for different sources, such as tubers and roots. Among the primary methods are traditional methods, which are focused on washing and grinding, and the others, which consider filtration and sedimentation, generally through wet and dry pathways.

3.1. Wet Pathway

The starch extraction method using wet pathways depends on the kind of tuber or root that will be extracted. The process of taro starch extraction [1] is carried out through the cleaning, peeling, and cutting of the taro, followed by filtration of the taro puree through a muslin bag to obtain a starch slurry. The starch slurry is left to rest, so the supernatant settles, before emptying it to produce an accumulated wet starch filtrate. This wet starch dries in the sun, is ground into a fine powder, and is almacened through its subsequent analysis.

The study of 'Extraction and characterization of the low-quality potatoes and the formulation of cookies without gluten that contains potato starch modified' is focused on the extraction of low-quality potato starch and the subsequent modification of the starch to improve its properties for use in cookies without gluten [2]. This research has the objective of using small and damaged potatoes that are usually discarded or used as animal aliments to extract starch via the production of aliments. The extraction process includes the preparation of raw material, the soaking of the potatoes in water, the separation of the starch in the aqueous solution, washing to remove impurities, and drying the starch. Starch modification is also mentioned, to improve the starch's functional properties.

Chinese yucca has a high content of starch and protein, which is why it is essential for the food industry [3]; for the extraction of starch, the tubers are cut, and then tubers are homogenized with the same weight of deionized water in the blender. The suspension is filtered across a 200-mesh sieve, the waste is washed twice with distilled water, and the filtered product is left to rest for two hours. After this, the supernatant is decanted, and the precipitate starch film is resuspended with deionized water. After repeating this eight times, the starch is suspended in ethyl alcohol and dried at 45 °C for 24 h after being collected by filtration through a 100-mesh sieve.

Taro (*Colocasia esculenta*) starch is extracted for its use in the production of biofilms [4]. The process consists of collecting 8 kg of taro peel, cleaning, cutting, and crushing it with a domestic beater until it becomes a paste. After that, the paste of the mixed taro peel is mixed with distilled water in a 1:2 weight/volume ratio. The mix is cleaned several times with oil to remove impurities, and the resulting liquid is left overnight, allowing for the starch to form as sediment on the bottom. The supernatant is removed to extract sedimented starch, collected, and washed to remove the remaining impurities; it is then dried in a hot-air stove at 30 °C for 48 h. Finally, the dry starch sample is crushed until it becomes dust using a commercial blender; the dust is sifted through 0.804 µm and 0.104 µm sieves to guarantee that particles of taro peel starch are of a uniform size. The final sample of taro peel starch is encased in reusable plastic bags after it is damascened in a digital wet controller and configured with a relative wetness of 50% and a temperature of ±25 °C for subsequent analysis.

There are several steps to extract pure starch from palmyra tubers. First, the tuber is washed and preparation with distilled water to remove pollutants; after this, it is peeled and cut into cubes of around 1 cm. Following this, the cubes of tubers are milled with a 1:4 weight/volume ratio of distilled water. The resulting mix is filtered using a double cotton fabric, and this process is repeated five times. Then, the filtered mix is left to rest for 24 h to allow for the starch to nod after it is decanted, and the top liquid is removed. Distilled water is added to the sediment; the mix is shaken, decanted, and removed from the top liquid. This process of washing is repeated until pure starch is obtained. Finally, the starch is put dried at 55 °C overnight, milled, sifted, and packaged in an airtight container [5]. The methodologies used to extract potato, yucca, and sweet potato are based on a wet extraction process (Figure 1) [6].

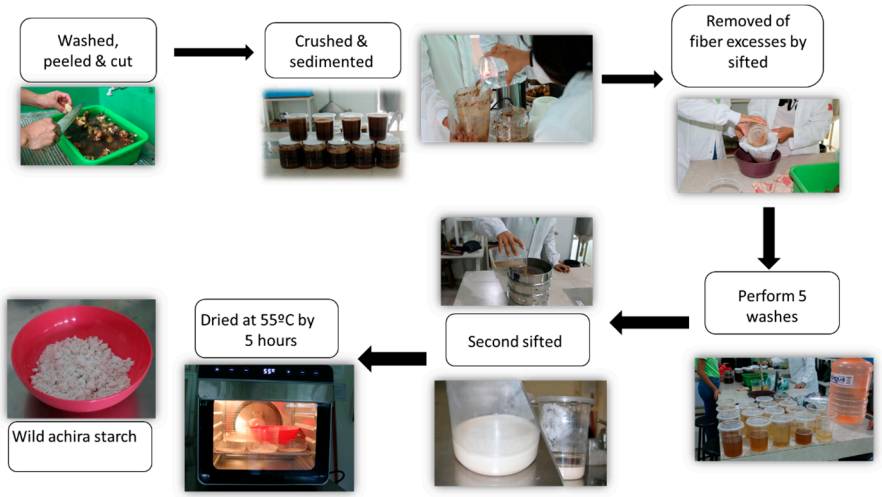

Figure 1. Conventional process of starch extraction from tubers and rhizomes using a wet pathway.

Starch is extracted from yam using a wet method [46]. First, the yam tubers are washed and peeled. After this, the tubers are cut into cubes and milled in a blender with water to obtain a mix of starch and water. The mixture is filtrated through a muslin fabric to separate the starch from the waste. The starch is left to rest, and the supernatant is removed. The starch is washed several times with water to remove all the impurities, and dried in shallow trays at a temperature of 20–25 °C for 24 h. Finally, the dry starch is milled in fine dust and stored in airtight bags for subsequent analysis.

Potato starch of the White Leona variety [7] is extracted via the preparation of the raw material, after which the tubers are washed, peeled, and cut into fine slices. The potato slices are crushed in a blender to obtain a pulp; this pulp is filtrated, and washed several times with distilled water to separate the starch from other components of the potato until the desired starch is obtained.

There are two extraction methods for *Canna indica* L. starch: the extraction method via liquification (LI) and the extraction method via grating (RA) [8]. The extraction method using liquification (LI) consists of cutting the *Canna indica* L. rhizome into little pieces and then liquifying it in a blender with distilled water. Subsequently, it is left in suspension for 3 h, the fiber is removed, and the sedimented starch is filtrated. Then, the starch is dried at 60 °C. The method of extraction using grating (RA) consists of grating the *Canna indica* L. rhizomes and then collecting the rhizomes in beakers with distilled water; this is left in suspension for 3 h, the fiber is removed, and the sedimented starch is filtrated. The starch is washed three times with distilled water and left to dry at environmental temperature for 48 h.

Hawthorn yam starch is obtained in several stages. First, fresh tubers are washed to remove the dirt, and then they are peeled to prepare them. Then, the tubers are reduced and liquefied with distilled water to form grout. This grout is filtered to separate the starch from the other components of the yam. The obtained starch undergoes a washing, decantation,

and filtration process in a vacuum to purify it. Subsequently, it is dried at 60 °C for 12 h to remove the wetness. Finally, the starch is milled and packed for use [9]. This process guarantees that high-quality hawthorn yam starch is obtained for use in the extraction of lactic acid.

The extraction of starch for yam and taro, two tubers underutilized in southeastern Nigeria, involves the following steps. Samples are obtained from different kinds of yam tubers (*D. cayenensis*, *D. dumentorum*, and *D. bulbifera*) and taro (*X. maffa Scoth*) from a local farmer in Nigeria [10]. The tuber samples are peeled, cut into pieces, and crushed in a commercial blender. The result of the suspension is filtered to obtain the starch; then, the starch is washed and dried in an oven with forced ventilation at 40 °C. The dry starch granules are sifted through a sieve with a pore size of 100 µm.

During the isolation of the starch from the Indian stick rhizome, the rhizomes are washed, peeled, and milled a thick paste is obtained. This is mixed with cold water and filtered through mustard cloth to separate the unwished particles. The starch suspension is left to rest, and the supernatant is decanted; the sediment is washed several times with fresh water until the supernatant becomes clear. The resulting starch is dried in air and collected in a container for subsequent use. This process allows us to obtain a potential yield of 12.5% of isolated starch from the base of the dry starch [11].

The extraction process of native starch clones from promising creole potato clones [12] is also realized following the wet pathway method. The tubers of creole potatoes are washed with a disinfectant solution of 200 ppm to remove any contamination. They are reduced into 0.01 m cubes using a vegetable processor and then crushed in a blender, and 0.005 kg of metabisulfite/L of water is added to avoid enzymatic browning. The ground mixture is filtered through a cloth, and the solid residue is washed several times with distilled water to remove all starch until the effluent liquid becomes clear. The washed residues is sedimented for one day, and the water is separated; the sediments are filtered with canvas to remove the remaining potato fibers in the starch. The resulting pastes are dried on aluminum trays at room temperature. Finally, the native starches are ground in a pulverizer mill and sieved to obtain starch with a particle diameter of 0.000149 m, which is stored in a suitable container.

Another technique used for wet yam extraction consists of peeling and cutting the yam tubers into cubes. The yam cubes are ground with water in a blender. The resulting mixture is filtered through a muslin cloth to remove impurities. The filtered liquid is passed through sieves of different sizes to eliminate unwanted particles—rapid liquid settling allows for the starch to settle. The supernatant is discarded and the starch pellet is redispersed in water, followed by repeated washing to obtain a clear pellet. The starch is dried at 30 ± 2 °C for 48 h and stored in suitable conditions for subsequent analysis [13].

This process allows for us to prepare pure and isolated yam starch to characterize and evaluate its physicochemical and functional properties.

To obtain taro starch [14], fresh rhizomes of white and purple taro, peeled and cut into cubes of 3 cm on each side, are used. They are then ground in a food processor for 2 min to reduce the particle size. The starch slurry is filtered through plastic cloth strainers (80 mesh) to remove fiber and other particles. The filtrate is allowed to settle for 4 h at temperatures of 4 °C. After this time, the supernatant liquid is decanted, and the starch slurry is washed three times with distilled water, centrifuging during the last wash with a centrifuge to recover the supernatant starch. Subsequently, it is dried in a convection oven at 55 °C for 24 h. The starch is then stored.

Another procedure for the wet extraction of cassava consists of washing the cassava roots and manually peeling them with a knife, then cutting them into pieces of 7–10 cm to facilitate the grating operation, producing a mass of cassava zest. The grated cassava dough is then passed through a metal strainer with double mesh and stainless-steel reinforcement, accompanied by a "blanket" cloth, separating the granules from the starch. It is washed with water, and the obtained slurry is allowed to settle for 8–12 h in a disinfected plastic container. Once the sedimentation period is over, the supernatant water and the water

"stain" are removed. A third part of the sedimented starch layer is placed in stainless steel trays and dried in an oven at 50 °C for 8–12 h, obtaining the native starch [15].

The extraction of the roots and tubers of *Ipomoea batatas*, *Arracacia xanthorrhiza*, *Colocasia esculenta*, *Xanthosoma sagittifolium*, and *Dioscorea trifida* (white and purple) cultivated in the Venezuelan Amazonian [16], begins with washing and peeling the roots and tubers The edible portion is cut into slices. Portions of the edible part are ground for 2 min in a blender with double the volume of distilled water. The homogenates are passed through a 200-mesh sieve. The crushing and screening operations are repeated four more times. The resulting suspensions are centrifuged at 1500 rpm for 15 min. After removing the mucilaginous layer, these pellets are washed several times by suspension in distilled water and centrifuged until they appear to be free of non-starch material. The sediments are dried in a ventilated oven at 45 °C. Each type of starch is passed through a 60-mesh sieve and stored at room temperature in sealed plastic bags inside airtight glass containers until further analysis.

Extracting starch from taro (*Colocasia esculenta* L. Schott) corm begins with peeling and washing the corms to remove dirt and mucilaginous substances. The corms are then cut into small pieces and scraped to obtain a paste. Then, the paste is homogenized with 0.015% $Na_2S_3O_5$ solution in a blender at high speed for 1.5 min. The homogenized paste is filtered through cheesecloth, and the residue is collected. The residue is homogenized once again with water to increase the extraction efficiency. The filtrate is sieved through 0.075 and 0.034 mm meshes and then centrifuged at 8000× *g* for 10 min. After centrifugation, the supernatant is discarded, and the precipitate is collected. The residue is mixed with water and centrifuged. This washing and centrifugation process is repeated twice. Starch is purified by adding 0.05 M NaOH and centrifuged at 10,000× *g* for 10 min to remove proteins. The supernatant is discarded, and the dark layer of insoluble components on top of the starch layer is scraped off. The starch is then washed with 0.1 M HCl to partially neutralize it and washed with chloroform: methanol (2:1) to remove lipids. Finally, the purified starch is dried in an oven at 40 °C, ground, and stored in glass jars at room temperature until use [17].

Starches are extracted from three cultures of *Dioscorea trifida* [18]. The roots are cleaned, rinsed with water, cut, and crushed for 2 min in a blender with double the volume of distilled water. The resulting suspension is passed five times through a 200-mesh sieve, and the sludge is centrifuged for 15 min at 1500 rpm. The sediment is washed with distilled water and dried in an oven at 45 °C. The starches are sieved (60 mesh sieve) and stored in an airtight container until analysis.

Starch extraction from the tubers of *Colocasia esculenta* (L.) Schott and *Xanthosoma sagittifolium* (L.) Schott was carried out by a washing and sieving process [47]. First, the tubers were peeled and washed to remove dirt and debris. They were cut into small pieces and soaked in water to release the starch. The mixture was then stirred to separate the starch from the residue and filtered through a fine mesh to obtain a starch slurry. The starch suspension was centrifuged to separate starch from residue and washed several times with water to remove residue and impurities. The starch was then dried in a low-temperature oven and sieved to obtain a fine starch powder. Finally, the obtained starch was characterized. The results showed that the starch extraction process was efficient and produced high-purity starch with a similar granule morphology to other types of starch.

The roots of Canna edulis starch were washed and disintegrated in a blender with enough water to form a suspension, and then filtered with a nylon filter medium (200 µm). The starch-containing filtrate was transferred to a container for starch sedimentation. When the starch settled, the supernatant was decanted, and fresh tap water was added. This step was repeated at least twice. Finally, the starch was dried in an oven at 40 °C with a moisture content of approximately 11% (weight) [20]. Starch samples were stored in a closed container until characterization studies were performed in the coming months.

Starch extraction from the different Dioscoreas [21] varieties was carried out by modifying the traditional wet method. The sweet potato tubers were washed, hulled, and sliced into approximately 1 cm cubes. The cubes were mixed with three volumes of distilled

water and blended at maximum speed for 5 min. Subsequently, the obtained suspension was centrifuged at 1500 rpm for 5 min. The supernatant (pulp) was liquefied and left to rest for 60 min. Then, it was filtered through a sieve with a mesh opening of 100 µm. The remaining solids were removed, and the filtrate was washed until the wash water was translucent, indicating that the starch had been extracted. The fraction containing the starch was dried in an oven at 40 °C for 24 h and then ground and sieved at 100 µm.

Another procedure to extract starch from taro (*Colocasia esculenta* L. Schott) consists of immersing taro flour (100 g) in an aqueous solution (3 L) at 35 °C for 12 h. The obtained suspension is homogenized for 30 min using a commercial mixer. The suspension is sieved using a 150 mm sieve and kept for 24 h until it settles. The raw starch is then collected and washed twice with water, dried for 48 h in an oven at 50 °C, and stored in sealed and dry bags until analysis [22].

The wet method uses the extraction and purification process of maguey starch (*Dioscorea trifida*), white and purple varieties [19]. This includes crushing the maguey samples, followed by washing and filtration to separate the starch from other components present in the plant material. Starch purification involves using techniques such as sedimentation and repeated washing to remove impurities and obtain a purer starch product.

Starch has also been obtained from red and white potato varieties by extracting non-parboiled samples using a filtration and sedimentation technique. The starch suspension is then washed repeatedly with distilled water and air-dried at room temperature and then at 60 °C for 12 h. The powder is then ground into fine starch flour [23].

The wet pathway method implies extracting starch from tubers by suspending the tubes in water before starch separation is carried out via sedimentation and filtration [37]. López et al. (2010) evaluated the extraction process used for *Pachyrhizus ahipa* roots; they used the wet milled method, and were looking to optimize the amount of water that was used, as well as the amount of washes that were needed [48]. The process begins with the treatment, washing, and selection of the roots to remove any impurities that may affect the extraction process. Following this, the optimum volume of water for the extraction process is determined, and the necessary repetitions are made to obtain better results regarding starch suspension and its subsequent sedimentation. After this, the roots are washed with chlorinated water to guarantee that the wastes are removed, and the microorganisms are left unwashed. Finally, the washed roots are stored at 4 °C to prevent fungus proliferation and maintain the roots' quality before extraction.

This method is relatively simple, producing a pure white starch with few chemical contaminants. However, starch extraction from other tubers can be more complex due to components like mucilages and latex, making starch granule sedimentation difficult and reducing the extracted starch's quality.

3.2. Dry Pathway

Starch extraction using the dry pathway technique implies drying, milling, and sifting the rhizomes or tubers, with each process differing according to the kind of raw material used.

The extraction of starch from yucca by the dry pathway can be achieved with two techniques. In the first technique, yucca is washed and peeled, grated, pre-dehydrated, pre-milled, dehydrated, milled, and sifted. The grating stage aims to crumble the pulp and break the cell walls to ease the release of starch granules. The pre-dehydration stage is realized with a temperature of 45 °C at three different levels: 20%, 30%, and 45% of residual wetness. The next stage is pre-milling at an intermediate humidity to achieve the initial separation of the fiber. The pre-milling consists of submitting the wet product to a compression force to ensure the initial separation of the fiber and the starch granules; this stage is realized in a ball mill for 10 min. The final dehydration was realized at a temperature of 60 °C until an absolute humidity of 12% was achieved. The sifting process has three different stages, using screens of 100, 90, 71, and 45 µm (Figure 2) [24].

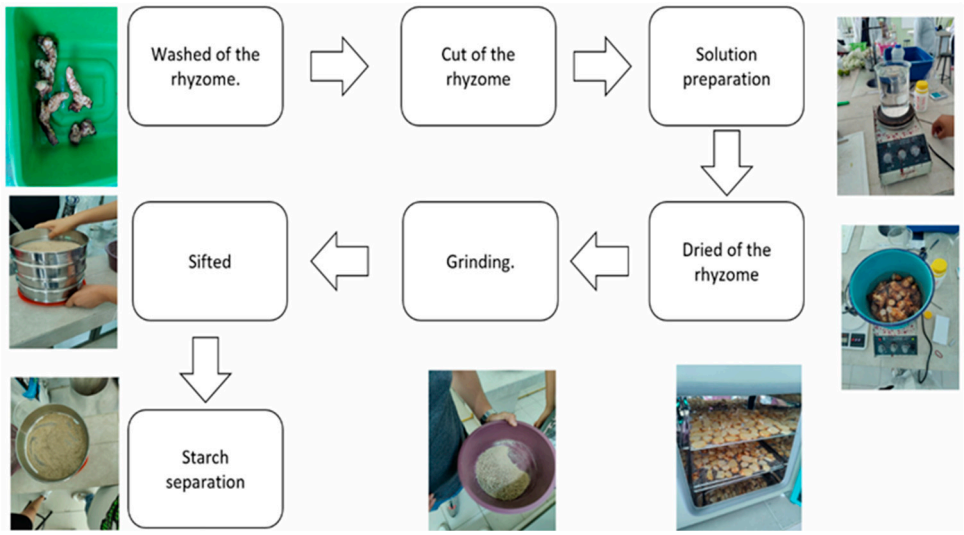

Figure 2. Conventional process of starch extraction from tubers and rhizomes using the dry pathway.

The starch extraction process used to obtain starch from *Xanthosoma sagittifolium* and *Colocassia esculenta* involves the following steps: sample preparation, in which three batches of clean tubers of *Xanthosoma sagittifolium* and *Colocassia esculenta* are obtained. In addition, commercial starch from *Manihot esculenta* is used as a control [25]. To prepare the sample for extraction, the clean tubers are peeled, weighed, cut, and ground for 2 min at high speed in a blender with distilled water. The resulting homogenization is passed through an 80-mesh sieve. This grinding and sieving operation is repeated four times. The resulting suspension is passed through 200- and 270-mesh sieves and centrifuged at 1500 rpm for 20 min. After removing the mucilaginous layer, the pellet is washed several times by suspension in distilled water and centrifugation until it appears to be free of non-starch material. The sediment is dried in an oven at 45 °C.

The dried starches of *Xanthosoma sagittifolium* and *Colocassia esculenta* are mixed, passed through a 60-mesh sieve, and stored in sealed plastic bags at room temperature.

There are two methods of starch extraction and protein recovery from the legume tuberous roots of *Pachyrhizus ahipa*: the traditional method and the proposed method [48]. The conventional method is based on starch extraction using water as a solvent. The chip roots are crushed, mixed with water, filtered, and left to rest for 24 h. Then, the mixing and filtration process is repeated six times to obtain the starch. This method is used as a comparison point for the proposed method. The proposed method is based on replacing water with a buffer solvent in the initial extraction stages. The chip roots are crushed and mixed with $(PO_4)^{-3}$/NaCl buffer (2 L of solvent per kg of root), filtered, and left to rest for 24 h. Then, the mixing and filtration process is repeated with water six times to obtain the starch. This method led to a significant improvement in protein extraction without affecting starch yield.

4. Mechanical Methods

Mechanical methods can include traditional methods, like the wet and dry pathways, which implies additionally crushing and pressing the raw material and centrifugation to improve the starch yield.

4.1. Pressing and Crushed

The process used to extract starch from taro husk for use in the production of biodegradable films [4], as well as from modified palmyrah tuber [5], involves milling, in which the dried starch sample is ground to obtain a powder using a commercial blender. Then, the powdered starch is pushed through sieves to ensure taro shell starch of uniform size are obtained.

Two methods of starch extraction from purple yam (*Dioscorea trifida*) involving grinding are presented: alkaline and aqueous extraction [27]. The purple yam sample was soaked in 0.1% NaOH solution for 18 h using alkaline and aqueous extraction methods. After washing, the purple yam was blended in a blender at high speed for 2 min. The resulting mixture was passed through a 63 µm sieve to separate the starch from other components.

In the extraction and characterization of potato starch (*Solanum tuberosum*) of the white lion variety [7], the potato slices are crushed in a blender to obtain a pulp; this operation is beneficial because, in this way, the raw material is easier to filter due to the consistency of the pulp, which is then washed several times with distilled water to separate the starch from the other components of the potato.

To extract starch process from inhambu [28], after the separation of impurities, the tubers are peeled and ground in a food processor. The resulting pulp is sieved through 0.149 mm and 0.079 mm meshes to remove fibers and other debris. The suspended pulp is washed four times with cold water and purified with absolute alcohol to remove impurities. It is then filtered and dried at 35 °C for 12 h in an air-circulation oven. The starch is ground through a 48 mesh to obtain a fine powder. The extraction method used in this study has been shown to produce starch with a high starch and amylose content, making it suitable for various industrial applications.

The method for extracting starch from Andean grains (amaranth, quinoa, and canihua) [29] consists of soaking the grains in a 0.25% (*w*/*v*) NaOH solution at five °C for 24 h. The grains are then crushed, and the mixture is filtered through a muslin cloth and sieves of different sizes. The final suspension is centrifuged at 2500× *g* for 15 min, and the upper yellow-brown-grayish layer is discarded. The remaining starch is resuspended in pure water and centrifuged again until the top layer is transparent. The isolated starch is dried in an oven at 40 °C for 48 h.

During the extraction of yam (*D. cayenensis*, *D. dumentorum*, and *D. bulbifera*) and taro (*X. maffa Scoth*) tuber varieties [10], tuber samples are peeled, cut into small pieces, and ground in a commercial blender. The resulting suspension is filtered to obtain the starch, which is then washed and dried in a forced ventilation oven at 40 °C.

The process of extracting native starch from promising Criolla potato clones [12] also involves crushing. The cubes are crushed after washing the Criolla potato tubers and reducing their size using a vegetable processor. To avoid enzymatic browning, 0.005 kg of metabisulfite/L of water is added to a blender.

In the achira starch extraction process [38], the rhizomes are washed with water to remove dirt and impurities. They are peeled manually with a knife and cut into 3 mm thick slices. The starch is washed two more times with distilled water and allowed to dry in the open air.

The extraction and purification of starch from mapuey varieties (*Dioscorea trifida*) [19] includes steps such as grinding mapuey samples to facilitate extraction.

4.2. Centrifugation

During the isolation and characterization of purple yam (*Dioscorea trifida*) starch, an alkaline and aqueous extraction was carried out [27]. In both processes, a centrifugation operation was used to separate the layers and recover the starch.

The production of oxalate-free starch from taro flour requires an oxalate oxidase-assisted process [30]. The starch extraction process includes the dispersion of different concentrations of taro flour in a buffer, followed by incubation at various periods with continuous shaking. Subsequently, the suspension is homogenized, sieved, and centrifuged. The sediment is washed with distilled water and isopropanol and dried to obtain starch.

To extract *Dioscorea opposita thunb* [31], Chinese yam tubers from both stages are washed, peeled, and cut into small pieces. The pieces are placed in an aluminum tray and dried at 45 °C for 24 h. The dried tubers are pulverized and passed through a 100-mesh sieve to obtain Chinese yam flour. The flour is soaked in an ethanol–sodium hydroxide solution (pH 8.5) for 12 h at room temperature. The supernatant os carefully decanted,

and the precipitated starch is washed five times with deionized water. Centrifugation is performed at 4000× *g* for 15 min to collect the starch. After drying the starch at 45 °C for 24 h, it is pulverized and passed through a 100-mesh sieve to obtain native Chinese yam starch.

The cassava starch extraction method involves the following steps. Cassava flour suspension: 60 g of cassava flour is suspended in 400 mL of deionized water at room temperature for 3 h. The suspension is centrifuged at 2000× *g* for 15 min at room temperature. After centrifugation, the resulting residue is extracted with the same amount of water to obtain the starch of cassava flour. This method allows for the extraction of starch from cassava flour for subsequent analysis [32].

Taro tubers were peeled, weighed, cut, and ground in 0.1% NaOH solution to extract taro starch from three cultivars planted in different seasons. The resulting suspension was filtered through a fine mesh sieve and then centrifuged to separate the starch. The starch pellet was neutralized with 0.1 N HCl solution, washed with water, and dehydrated with ethanol [33]. Finally, the starch was air-dried in an oven at 40 °C.

Fresh makal rhizomes were used to extract starches. (*Xanthosoma yucatanensis*), Sweet potato (*Ipomea batata*), cassava (*Manihot esculenta*), and sago (*Marantha arundinacea*) were peeled and cut into cubes of 3 cm on each side and were soaked for 30 min in a bisulfite solution of sodium with a concentration of 1500 ppm, in a 1:3 (*w*/*v*) ratio [34]. The cubes were ground in a food processor to reduce the particle size. The resulting mass was transferred to containers containing a sodium bisulfite solution at a concentration of 1500 ppm SO_2 in a 1:1 (*v*/*v*) ratio. The starch slurry was filtered through plastic cloth strainers (80 mesh) to eliminate fiber. The filtrate was allowed to settle at 4 °C for 4 h. After this, most of the supernatant liquid was removed by siphoning, and the starch slurry was washed three times with distilled water, centrifuging in the last wash at 2500 rpm for 12 min to recover the starch. Subsequently, the starch was dried in a convection oven at 55 °C for 24 h.

The isolation of taro starch involves cutting taro roots into slices and air-drying them at 40 ± 2 °C. They are then ground with a hammer mill and sieved to obtain taro flour. The taro flour is soaked in a 2% NaCl solution for five hours at 40 °C with constant stirring. After this, the mixture is filtered through an 80 µm mesh and settled overnight. The resulting residue, which consists of the starch pellet, is treated with 0.03 M NaOH and centrifuged at 4500 rpm for 15 min. The residue is washed twice with distilled water and once with ethanol to remove impurities. Finally, the starch is dried at 30 °C and collected in a sealed container. Before its use in analysis, the starch is ground with a mortar and pestle and stored [35].

A yellow-skinned potato starch extraction process was carried out as follows: 600 g of yellow-skinned potatoes were washed, peeled, and cut into small pieces. Distilled water was added to the potatoes, and the extraction process was carried out using a centrifuge at different speeds (1000, 2000, 4000 rpm) for various periods (5, 10, 15 min). Then, the centrifuged samples were filtered, and the supernatant was discarded to obtain the wet starch. The damp starch was dried at room temperature for five hours, ground into a fine powder, and stored in sealed containers for later use [36]. The process involved both experiments and an analysis of variance to determine the optimal processing conditions. It was found that a centrifugation speed of 3000 rpm and a time of 15 min produced the highest yield of extracted starch.

The starch extraction method used in the study of Pachyrhizus tuberosus, according to Ascheri et al. (2004), began with obtaining of fresh roots, which were used for five different phenotypes of *Pachyrhizus tuberosus* [49]. The roots were immersed in successive washes to remove impurities and unwashed pollutants; starch was separated via the suspension of the unwished material through decantation. Subsequently, centrifugation was carried out to separate the starch from other components. Finally, the obtained starch was immersed using a freeze-drying, dry process in which the product was frozen and the water was removed by sublimation, maintaining the structure and starch properties.

5. Enzymatic and Chemical Methods

The use of solvents and certain enzymes, in some cases, improves the yield of starch extracted from tubers and rhizomes; if this is added to traditional and mechanical methods, it can provide better conditions for obtaining starch.

5.1. Solvents Use

To extract starch from Chinese cassava, after repeating the process eight times, the starch was resuspended in ethyl alcohol, dried at 45 °C for 24 h (approximately 10% humidity), and collected by filtration through a 100-mesh sieve [3] for later interaction with proteins. The results showed that the interaction between protein and starch improved the starch's gelatinization and pastification properties, as well as its solubility and swelling power. Furthermore, starch's digestibility was reduced due to interaction with protein.

As a first step, the extraction of starch from wild yam involves washing the tubers with distilled water, followed by peeling, cutting, and homogenizing the tubers with a blender. The resulting suspension is mixed with 4% $Na_2S_2O_3$ solution and filtered through a muslin bag. The filtrate is allowed to sit for five hours, allowing the moist starch cake to settle to the bottom before decanting. The wet cake is then washed with distilled water and decanted several times to obtain a pure damp-starch cake. Finally, the cake is dried in aluminum foil at 50 °C for 24 h and stored in transparent polyethylene film at 4 °C before analysis [39]. This process is essential to obtain pure starch for a subsequent analysis of its physicochemical properties.

The alkaline extraction method used to isolate starch from purple yam (*Dioscorea trifida*) [27] involved the following steps: The purple yam sample was soaked in 0.1% NaOH solution for 18 h. The purple yam was then blended in a blender at high speed for 2 min. The resulting mixture was passed through a 63-mesh sieve to separate the starch from other components. The mixture was centrifuged at room temperature to separate the layers and recover the starch. The recovered starch was washed with NaOH solution and deionized water to remove impurities. The starch was neutralized with 1.0 mol L 1 hydrochloric acid (HCl) until a pH of 6.5 was reached. Finally, the starch was dried at 40 °C for 24 h and stored at room temperature for further analysis. This alkaline extraction method allowed for purple yam starch to be obtained for its subsequent characterization and an evaluation of its properties.

Oxalate-free starch was produced from taro flour using an oxalate–oxidase-assisted process [30]. The optimal treatment involved the suspension of 4% taro flour in a succinate/NaOH buffer (pH 3.8) with one mM $MnSO_4$, with an oxalate–oxidase loading of 100 U/mg, before incubation for 150 min at 55 °C. This innovative approach has important implications for the food industry and other starch applications, as it allows for aro starch with unique properties and without oxalates to be obtained, which expands its potential use in various industrial applications.

The extraction and characterization of starch from Ariá (*Goeppertia allouia*), a tuber of the araruta family that is widely found in the Brazilian Amazon [40], begins by washing the tubers, which are disinfected with a sodium hypochlorite solution at 200 ppm. Tubers are then peeled and ground at a 1:2 tuber/water ratio. The mixture is filtered and left for 15 h at 4 °C to decant the starch. The supernatant is removed, and the starch is washed with distilled water. The starch paste is dried in an oven at 40 °C for 16 h. After drying, the starch is stored in plastic packages at room temperature until further use.

The wet method describes the starch extraction method used for Chinese yam in the expansion and dormancy stages [31]. Native and resistant starch from Chinese yam tubers at both stages was prepared, and their properties were analyzed. To prepare resistant starch, native starch was suspended in sodium acetate solution (pH 5.2) and incubated at 37 °C for 10 min. Pancreatic starch and amyloglucosidase were added and incubated at 37 °C for 120 min. Finally, ethanol was added to stop digestion, and centrifugation was performed to collect resistant starch.

The extraction of starch and the recovery of proteins from the leguminous tuberous roots of *Pachyrhizus ahipa* [26] was carried out using a proposed method, which was based on the replacement of water with a buffered solvent $(PO_4)^{-3}$/NaCl in the initial stages of extraction. This method allowed for a significant improvement in protein extraction without affecting starch yield.

To obtain, modify, and characterize native and acetylated taro starch, an acetylated starch with a degree of substitution (DS) of 1.7 was obtained, which led to an increase in its functional properties compared to native starch [41].

Starch extraction from the rhizomes of *Cyperus alulatus* [42] involves collecting rhizomes and washing them with distilled water to remove dirt and other contaminants. They are then cut into small pieces of 2–3 cm length and soaked in 0.05% sodium hydroxide solution for 24 h at room temperature. After soaking, the excess solution is washed off, and the mixture is ground to form a slurry. The slurry is passed through a sieve to separate the starch from unwanted solids. The starch settles to the bottom of the container and the supernatant liquid is separated. The settled starch is collected and dried in the open air.

Achira is a plant native to the Andes in South America, and its cultivation has expanded to different tropical countries, such as Brazil [38]. An important step to obtain starch from this plant consists of treatment with a preservative solution, where the rhizome slices are immersed in a 0.5% $K_2S_2O_5$ solution for 15 min at a temperature of 38 °C. They are then removed from the solution and allowed to sit for an additional 15 min in a 0.8% $K_2S_2O_5$ solution to prevent oxidation. The rhizome slices are disintegrated in a blender with 0.5% $K_2S_2O_5$ solution at a ratio of 1:2 (rhizomes–solution). The mixture is filtered through a 60-mesh sieve to separate the bagasse from the starch, allowing for the washing, sedimentation, and recovery of the starch (Figure 3).

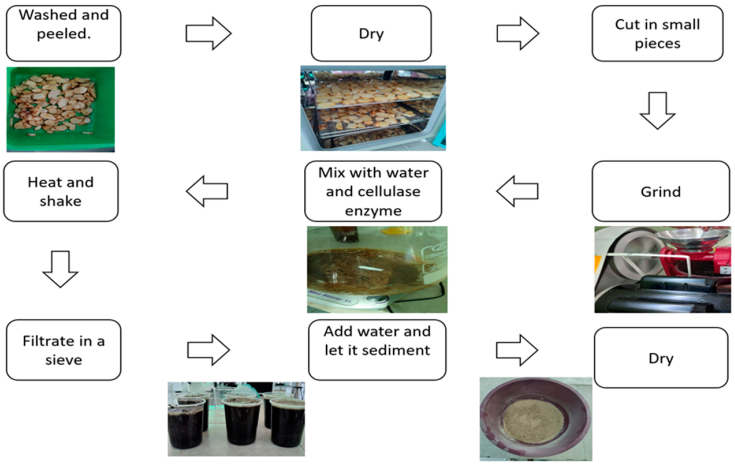

Figure 3. Conventional process for starch extraction from tubers and rhizomes via the enzymatic method.

The process of starch extraction from taro (*Colocasia esculenta* L. Schott) corm [17] involved peeling and washing the corms, followed by scraping and homogenization, in which the use of solvents was involved since the corms were cut into small pieces and scraped to obtain a paste. Then, the paste was homogenized with a 0.015% $Na_2S_3O_5$ solution in a blender at high speed for 1.5 min. Finally, filtration, sieving and centrifugation, purification, and drying of the starch were carried out.

Taro starches from three cultivars planted in different seasons were peeled, weighed, cut, and ground in a 0.1% NaOH solution to facilitate extraction. Then, the resulting suspension was filtered through a fine mesh sieve and centrifuged to separate the starch. The starch pellet was neutralized with 0.1 NHCl solution, washed with water, and dehydrated with ethanol; finally, the starch was air-dried in an oven at 40 °C [33].

Starch extraction with ammonia solutions involves the use of ammonia solutions to improve the extraction of starch from tubers such as cassava, yam, and taro. The ammonia

solution acts as a complexant that helps release the starch granules and reduce the viscosity of the starch suspension [37]. This method has proven to be effective in improving starch extraction yield and producing high-quality starches.

Four extraction methods were evaluated regarding the characteristics of starch extracted from *Dioscorea alata.* Diauto et al. (2005) conducted a study using *Discorea alata* tubers at their maximum stage of physiologic development, with a humidity content of 76.1%. The extraction methods included water, pectinase, NaOH, and oxalic acid/oxalate [50].

Next, each of the methods that were used are described. The first is extraction with water (control), where the pieces were milled in water and then filtrated, decanted, and sifted, using two decantation processes. The second method is extraction with pectinase, which uses pectinase in the process, resulting in a variation in starch granule size in comparison with extraction with water. The third method is extraction with NaOH; this one uses NaOH, which could affect the granule's structure and lead to a high peak in viscosity in comparison to the control. The last method is extraction with oxalic acid/oxalate; this method uses oxalic acid/ammonia oxalate, simplifying the separation of the starch suspension and allowing for better starch recuperation with a granular variation.

The extraction of starch from many sources, such as potatoes, corn, and yucca, that was used in another study included a sodium metabisulfite solution. This solution was used to extract starch from the mentioned sources. The percentage yield of starch obtained from all the sources was found to be satisfactory. Once the starch was extracted, pregelatinized starch and carboxymethylated derivatives were prepared via pharmaceutic excipients to evaluate their subsequent properties [51].

5.2. Use of Specific Enzymes

Starch was extracted from potatoes in the study 'Enzymatic extraction of starch from potatoes…' in several stages. First, fresh potatoes were washed and dried before being cut and ground to obtain uniform potato flour. Then, the potato flour was transferred to a conical flask, and an appropriate amount of water was added for each experiment. Next, 1 g of enzyme was mixed in 10 mL of water with a glass rod. For a concentration of 0.1 g/100 g of potato flour, 1 mL of enzyme solution was added to 100 g of potato flour. The mixture was heated and filtered before drying the recovered starch. The study used a response surface methodology to optimize the extraction parameters, including enzyme concentration, contact time, and broth dilution.

Enzymatic starch extraction involves using enzymes such as pectinase and cellulose to improve the starch extraction yield of tubers such as cassava and sweet potato [52]. The enzymes alter the integrity of the pectin–cellulosic matrix of cell membranes and facilitate the release of starch granules. This method has proven to be effective in improving starch extraction yield and producing high-quality starches.

In the study by Sit et al. (2015), tuberose taro (*Colocasia esculenta* var. antiquorum) was used for starch isolation [52]. The starch extraction method using enzymes involved the preparation of taro tubers, where taro tubers were washed, peeled, and cut into cubes of about 1 cm in size. Then, 100 g of taro cubes were milled using a laboratory blender for 1 min and 30 s. In the enzymatic treatment, a combination of cellulase and xylanase enzymes was used, with different cellulase concentrations (0–100 U/100 g of tubers) and xylanase concentrations (0/100 U/100 g of tubers), as well as different incubation temperatures (30–50 °C) and incubation times (1–5 h). A rotative central compound design (CCRD) with four numeric factors was used to design the experiments and optimize the starch extraction process. The effects of the different factors on starch yield were analyzed and the optimum conditions to maximize yield were determined [52].

6. New Methods for Starch Extraction

Many different methods and techniques allow for better efficiency and an improvement in yield percentage. These methods include the technique based on ultrasound (Figure 4) and the technique based on pulse electric field assistance, which have been used

to extract other compounds, such as polyphenols. These technologies are advantageous for extracting bioactive compounds for food applications and are regarded as green technologies since they do not require harmful chemicals. Compared with the traditional methods, these methods present several advantages, such as a shorter extraction time and lower energy requirements. Both methods are considered non-thermal extraction methods.

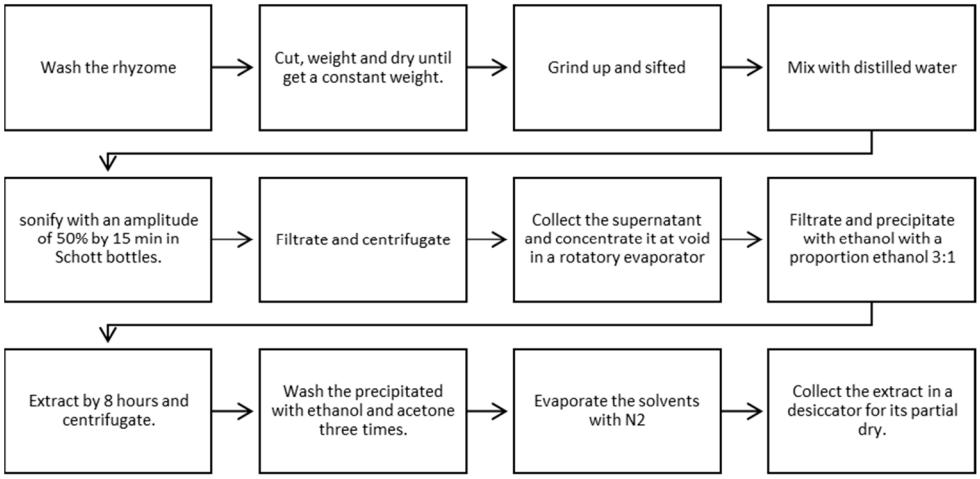

Figure 4. Starch extraction from tubers and rhizomes using an ultrasound-assisted method.

The extraction of Tp-WS-NSP via the ultrasound method led to a significantly higher yield than that of Tp-WS-NSP extracted using the pulse electric-field-assisted method [53].

The technique using pulsed electric fields (PEF) is a non-thermal food-processing technology that applies short-duration electric pulses with electric field intensities of up to 80 kV/cm. It has shown the potential to physically modify the native properties of starch from various sources. The PEF techniques allow for improved starch extraction and alter starch's properties by decreasing the relative crystallinity, gelatinization temperatures, enthalpies, viscosity, and pasting temperature. This method has different advantages regarding the extraction and also the modification of the starch's properties. This has led to a better efficiency than the traditional methods used to modify starch properties. It also allows for a more sustainable process, avoiding the use of chemicals, high operation temperatures, and prolonged operation times [54].

The use of these new methods provides us a with grand vision of the future of the starch extraction industry. The use of these kinds of techniques presents more advantages and there are differences between each method. As each method can be used to increase yield, we are going to focus on the ultrasound method, which has delivered a better yield compared with the PEF method and the traditional methods. On the other hand, if we were looking for a technique that provides better conditions to modify the starch's properties, the PEF method would be the best option. This physical method has shown a remarkable capacity for changing the starch's properties, providing a low-cost, higher-efficiency, and more sustainable process.

7. Comparison of the Efficiency of the Methods

The starch yield obtained from the different tubers and rhizomes can vary according to several factors, such as the raw material, the extraction method, and the process conditions. The obtained starch yield can be calculated by dividing the initial amount that is recovered by the initial amount of raw material used.

7.1. Starch Yield

In the extraction of starch from anchote roots (*Coccinia abyssinica*), according to the study, the obtained yield was 70.41 ± 0.35% [55]; this means that a significant amount of starch was obtained from the anchovy roots used in the study.

In the study of starch extraction from low-quality potatoes, the yield varied between 10.5% and 12.5% depending on the variety of potatoes used [2]. These results suggest that extracting starch from low-quality potatoes may be profitable and sustainable, as a significant amount of starch that would otherwise be considered waste can be obtained from potatoes.

The starch extraction yield of Ariá was around 11% *w*/*w* from a tuber with a moisture content of 84% [40]. This performance may have been due the easy removal of the skin and the low amount of proteins and lipids in the tubers, which facilitates rapid starch extraction. The extraction process was carried out with water only, without the need for reducing agents to break protein bonds or inhibitors of enzymatic activity.

The enzymatic extraction of potato starch achieved an optimal starch yield of 89% under specific conditions when using a response surface methodology to optimize the extraction [43]. This performance was achieved by considering enzyme concentration, contact time, and broth dilution as crucial parameters in the extraction process.

The yield of starch obtained from inhambu was reported as the percentage of the weight of the extracted starch regarding the weight of the raw material. According to the study, the starch yield was 22.76% [28]; this high yield indicates the efficiency of the extraction process and the abundance of starch in the inhambu.

The starch yield of Chinese yam was calculated by dividing the weight of the isolated starch by the weight of the flour used in the extraction process. According to the study, the starch yields in the expansion and dormancy stages were 63.4% and 61.2%, respectively [31]. These values indicate the efficiency with which starch could be isolated from Chinese yam tubers at different growth stages.

The starch yield obtained in potato starch extraction varied depending on the processing conditions used. The optimal processing conditions for extracting potato starch from yellow skin were a centrifugation speed of 3000 rpm and a time of 15 min, which produced the highest starch yield [36]. The starch yield was measured as a percentage and determined by the weight of the extracted starch and the initial weight of the potatoes used in the extraction process.

The yield of starch obtained from the rhizomes of *Cyperus alulatus* was calculated by dividing the weight of the obtained starch powder by the initial weight of the rhizomes used for the extraction [42]. The starch yield was 11.93%.

The yield of native starch extraction depends on the tuber's dry matter and starch content. In the study of promising Creole potato clones, it was found that some clones with a higher starch content did not lead to a higher yield due to the tuber's maturity at the time of extraction. The average yield of native starch was 12.5% for the promising Creole potato clones that were evaluated [12].

Based on the weight of fresh rhizomes, the yields for achira flour and starch of Brazilian origin were 13.2% and 6.3%, respectively [38]. These yields were considered low compared to other studies that reported higher starch yields for older achira rhizomes.

The starch yield values obtained for the different *Dioscorea trifida* crops and the commercial crop were as follows [18]:

- Amazonian White (AW): 19.0 ± 0.0%;
- Amazonian Light Purple (ALP): 17.5 ± 0.1%;
- Amazonian Dark Purple (ADP): 16.1 ± 0.0%;
- Commercial White (CW): 22.5 ± 0.1%.

Starch yield values were calculated as the ratio of the dry starch's weight to the edible portion's weight.

According to the study, the yield of starch extracted from cassava was approximately 231–234 kg of sour starch per 1000 kg of processed cassava; this represents a production efficiency between 51% and 59% [56].

The starch yield percentages of Dioscoreas, according to their dry weight, ranged from 22.10% to 35.79%, which is higher than that reported for other Dioscoreas species, such as D. esculent and *D. alata* (12.2–18.0%) [19]. This high yield of starch from the dioscorea tuber

species *D. remotiflora* and *D. sparsiflora* suggests significant potential for application in the food industry and other areas requiring high-quality starches.

The starch yield obtained via the cassava dry extraction process varies depending on the pre-grinding, grinding, and sieving conditions [24]. In the second extraction technique evaluated in the study, a pre-grinding humidity of 20%, a grinding time of 30 min, and a sieving speed of 140 rpm were used. The average yield of all the final products for all combinations of the second technique shows that the maximum yield was 100% for a mesh size of 71 µm, while the minimum yield was 45% for a mesh size of 100 µm.

The yield for Xanthosoma sagittifolium and Colocasia esculenta tubers was 10–12% according to dry weight; this means that, for every 100 g of dried tubers, between 10 and 12 g of starch was obtained. This performance is similar to that obtained in other studies of starch extraction from tubers and roots [25].

López et al. (2010) reported a yield of 11.31% in wet weight and 56.54% in dry weight in *Pahyrhizus ahipa* roots [48].

The yield of starch obtained from potato, cassava, and sweet potato indicates that, from an initial weight of 1 kg of each product, a total of 97.20 g of potato starch and 204.00 g of cassava starch was obtained, and 95.10 g of sweet potato starch. These values represent the starch yield obtained through the extraction process, showing that cassava produced the highest amount of starch compared to potato and sweet potato [6].

Rahman et al. (2003) highlighted the importance of choosing the appropriate sweet potato variety to maximize starch extraction per cultivated hectare. They suggested that starch extraction varies significantly between different sweet potato varieties, meaning that starch extractability should be considered when developing varieties with a higher starch content. They obtained a starch extraction yield that varied between 70.6% and 96.5% in the dry season and between 47.6% and 96.5% in the wet season through repeated homogenization. The average starch extraction yield was 80.2% in dry seasons and 65.8% in wet seasons [56]. These results indicate that the starch extraction performance of the studied sweet potato varieties was influenced by factors such as the harvest season and the homogenization process.

The enzymatic extraction method using a combination of cellulase and xylanase allowed for a significant increase in the starch yield of taro tubers, and the properties of the starch obtained with this method were compared with those of starch obtained by conventional methods. Sit et al. (2015) found that using enzymes significantly increased the starch yield of taro tubers; a maximum starch yield of 17.22% was obtained using the optimized enzymatic extraction method. Starch yield may vary depending on the extraction conditions, enzymes used, enzyme concentrations, temperatures, and incubation times [52].

It is important to note that starch yield can vary depending on factors such as rhizome age, growing conditions, extraction method, and other process-specific factors (Table 2).

Table 2. Comparison of the yield obtained using different starch sources and traditional methods.

Method	Starch Source	Yield	References
Wet	Low-quality potatoes	10.5–12.5%	[2]
	Potato	9.72%	[6]
	Yucca	20.40%	[6]
	Sweet Taro	9.51%	[6]
	Creole potato	12.50%	[14]
Mechanical	Amazonian White (*Dioscorea trifida*)	19.0%	[18]
	Amazonian Light Purple (Dioscorea trifida)	17.5 ± 0.1%	[18]
	Amazonian Dark Purple (Dioscorea trifida)	16.1 ± 0.0%	[18]
	Commercial White (Dioscorea trifida)	22.5 ± 0.1%	[18]

Table 2. *Cont.*

Method	Starch Source	Yield	References
Wet	*Dioscorea trifida*	22.10–35.79%	[19]
	D. esculenta y *D. alata*	12.2–18.0%	[19]
Dry	Yucca	45%	[24]
	Xanthosoma sagittifolium y *Colocasia esculenta*	10–12%	[25]
Mechanical	Inhambu	22.76%	[28]
	Achira	6.30%	[38]
	Ñame chinase (*Dioscorea opposita thunb*)	61.2–63.4%	[31]
Wet	Ariá (*Goeppertia allouia*)	11%	[40]
Enzymatic	Potato	89%	[43]
Chemical	*Cyperus alulatus*	11.93%	[42]
Wet	Anchote (*Coccinia abyssinica*)	70.41 ± 0.35%	[55]
	Yucca	51–59%	[57]

7.2. Quality Evaluation of the Extracted Starch

The starch extracted from anchote showed satisfactory physicochemical and functional properties, with a pH of 4.44, water retention capacity of 112%, solubility of 5.03%, swelling power of 5.781%, gelatinization temperature of 53.33 °C, water absorption capacity of 2 g/g, bulk density of 0.605 g/cm^3 and oil absorption capacity of 3 g/g [55]. These characteristics indicate that anchote starch has properties that could benefit various industrial applications.

Ariá starch exhibited several properties that suggest its quality and potential for food applications. One of the characteristics of Ariá starch is its amylose content, which is around 39%, which places it in a range similar to that of other high-quality starch sources; it also contains a Type-C crystalline structure, which suggests a unique organization that may influence its functional properties, and exhibits gelatinization behavior and swelling properties that make it suitable for use in food applications, such as moisture control and food stability. Ariá starch has unique rheological properties, including a higher paste clarity and gel strength than other commercial starches [40].

These characteristics suggest that Ariá starch is suitable for the food industry and may represent a high-quality alternative to conventional corn and potato starches.

Physical–chemical tests characterized potato starch of the Leona Blanca variety. The moisture content of the starch was 12.660%, which is within the compared ranges and indicates the stability of the product. However, the ash content was 0.853%, a higher value than others found in the comparison, related to the increased mineral content in the potato starch [7].

The starch obtained from hawthorn yam was characterized to determine its quality. The starch was found to have crude fiber, ash, fat, protein, residual moisture, and amylose contents. In addition, it was determined that the starch comprised 73.22% amylopectin, 28.7% amylose, 7.64% crude protein, 0.26% total fat, 0.88% crude fiber, and 8.26% moisture. These parameters indicate the quality and composition of the obtained starch, suggesting its suitability for use in the production of lactic acid and possibly in the production of food products [9].

The amylose content in Brazilian achira starch was 23.5%, while the amylose content in Colombian starch was 28.5%. These values are considered high compared to other tuber starches. The X-ray diffraction (XRD) pattern of Brazilian and Colombian achira starch showed a type B pattern with a relative crystallinity of 27.0–28.0%; this indicates that achira starch is relatively crystalline. A differential scanning calorimetry (DSC) analysis showed that Brazilian and Colombian achira starch have a gelatinization temperature of 68.5 °C and 70.5 °C, respectively [38]. These values are considered high compared to other tuber starches. Brazilian and Colombian achira starch showed high swelling power and solubility in hot water, indicating that these starches can retain water and form gels.

The starch extracted from the tubers of *Colocasia esculenta* (L.) Schott and *Xanthosoma sagittifolium* (L.) Schott had a high purity grade, with a 12.7% and 26.2% amylose content

for the Chinese and Creole ocumos, respectively. In addition, the starches had a high initial gelatinization temperature, resistance to mechanical disintegration, excellent cooking stability, and an increased tendency toward retrogradation. The morphology of the starch granules was similar to that found in the literature for this type of starch, with rounded large granules and a polyhedral shape for the small ones. Furthermore, a low accumulation was observed in granules smaller than 4 mm, indicating that the starches are native [25].

The amylose content of taro starch varied between 8.7% and 14.9%, suggesting significant differences in its gelatinization and plastification properties [4].

The average size of taro starch granules was determined to vary between 2.37 µm and 2.79 µm, which is essential for their functionality in culinary and industrial applications. Elasticity measurements were made during gelatinization, providing information on the ability of the starch to form gels and its behavior during heating. These parameters are essential to understanding the quality and functionality of taro starch in various applications, from the food industry to the production of bioplastics and adhesives.

The starch quality obtained by drying cassava was evaluated based on several physicochemical parameters, such as cleanliness, granulometry, color, odor, moisture content, fiber, ash, acidity, and viscosity. In the study, it was found that the starch obtained by the dry method had a lower fiber content compared to the starch obtained by the wet process. Furthermore, the product obtained by this method can be considered a partially modified starch due to the high sugar content (20%), indicating the partial hydrolysis of the starch during the extraction process [24]. Applicability tests of the product were carried out regarding the production of adhesives for toilet paper cones, obtaining satisfactory results.

Starch from potatoes is utilized in the food industry due to its low gelatinization and low retrogradation tendencies. The starch from yucca is used more frequently in the industry, and its size can vary from 5 to 35 um; its shape is round and flattened, and its amylose content is around 17%. Sweet potato flours have good stability, high viscosity, and a relatively high gelatinization temperature, making them suitable for preparing heat-resistant foods with a high viscosity, such as hard confectionery, and preparing children's foods [6].

According to Sukhija et al. (2015), the physicochemical characteristics of starches isolated from different sources, such as elephant yam, taro, ginger, green banana, and lotus stem, include significant variations in properties such as size and shape, starch granules, crystallization pattern, and thermal and gelation properties. It was observed that taro starch had the smallest granule size, with a clustering pattern, while lotus starch granules were the largest, with hemispherical facets and indentations or cavities at one end. This suggests differences in the structure and distribution of starch granules between different tuberous sources [58]. Furthermore, it was found that lotus stem starch had the lowest level of gelatinization, as well as the lowest start, peak, and end temperature values. These differences in thermal properties can affect the gelatinization capacity and stability of starches during thermal processing.

According to Biswal et al. (2022), the starch derived from the fleshy root tuber of Phoenix sylvestris has several important characteristics, such as shape, since the starch granules are found in oval and spherical shapes, with an occasional floral structure, due to their interactions with proteins [59]. Furthermore, the obtained is of high purity, with an amylose content of 62.39 g per 100 g of starch. Starch's granular size is 1–10 µm; it is suggested that *Phoenix sylvestris* starch has promising technological and functional properties and could be used for various food, biomedical, and industrial applications.

These results provide information on the quality of the extracted starch, which may be relevant to its possible application in the food industry. All these properties offer a perspective of the extracted starch's quality, depending on the starch source and the extraction method. The compositional and physiochemistry properties are essential for selecting the method and starch source that will be used in a process, and these data can provide us with a basis for improving and optimizing the methods. Starches' compositional and physiochemistry properties are presented in the following tables (Tables 3 and 4).

Table 3. Chemical characteristics of starches.

Starch Source	Particle Size (μm)	Solubility (%)	Swelling Power (%)	Stability	Turbidity	Gelatinization Temperature (°C)	Water Absorption Capacity (g/g)	Bulk Density (g/cm^3)	Oil Absorption Capacity (g/g)	References
Palmyrah (*Borassus flabellifer* L.)	6.5841	0.92	3.47	ND	ND	76.5	ND	ND	ND	[5]
Canna indica L.	ND	0.15	4.39	ND	ND	75.6	4.37	ND	ND	[8]
Inhambu (*Dioscorea trifida* L.)	5.06–15.44	ND	ND	ND	ND	ND	ND	ND	ND	[28]
Yucca (*Manihot esculenta*) "Valencia" variety	14	ND	ND	ND	ND	ND	ND	ND	ND	[15]
Yucca (*Manihot esculenta*) "Brasileña" variety	12.8	ND	ND	ND	ND	ND	ND	ND	ND	
Mapuey (*Dioscorea trifida*) purple variety	30.33	1	4.18	ND	ND	77.5	3.18	ND	ND	[19]
Mapuey (*Dioscorea trifida*) white variety	34.15	3.21	7.93	ND	ND	75.1	6.93	ND	ND	
Andean Achira Roots (*Canna edulis*)	ND	ND	ND	79	ND	67.8	ND	ND	ND	[20]
Sweet potato white-skinned variety	>40	ND	ND	ND	ND	74.8	15	ND	12	[23]
Sweet potato red-skinned variety	>40	ND	ND	ND	ND	75.7	15	ND	10	
Xanthosoma sagitifolium (tannia)	2.0–12.5	ND	ND	ND	ND	93.8	ND	ND	ND	[25]
Colocasia esculenta (taro)	0.5–5.0	ND	ND	ND	ND	89.7	ND	ND	ND	
Purple yam (*Dioscorea trifida*)	24.11–45.37	ND	ND	ND	ND	90.02	ND	ND	ND	[27]
Achira (*Canna indica* L.) variety Brazilian	13–128	ND	ND	ND	ND	ND	ND	ND	ND	[38]
Achira (*Canna indica* L.) variety Colombian	13–90.5	ND	ND	ND	ND	ND	ND	ND	ND	
Makal	12.4	ND	28.56	ND	ND	78.4	ND	ND	ND	[34]
Sweet potato	12.41	ND	25.53	ND	ND	61.3	ND	ND	ND	
Yucca	16.5	ND	58.83	ND	ND	65.2	ND	ND	ND	
Sagú	10.64	ND	16.98	ND	ND	74.9	ND	ND	ND	
Ariá (*Goeppertia allouia*)	10	ND	ND	ND	ND	8.46	ND	ND	ND	[40]
Anchote (*Coccinia abyssinica*)	ND	5.03	5.781	1.348	1.134	53.33	200%	0.605	300%	[55]
Ocumo criollo (*Xanthosoma sagittifolium* (L.) Schott)	2.2–10.4	ND	ND	ND	ND	ND	ND	ND	ND	[25]
Ocumo chino (*Colocasia esculenta* (L.) Schott)	0.4–12.0	ND	ND	ND	ND	ND	ND	ND	ND	

ND: Not determinate.

Table 4. Compositional characteristics of starches.

Starch Source	Amylose (%)	Amylopectin (%)	Ph	Moisture Content (%)	Ash (%)	Crude Protein (%)	Lipids (%)	Total Fibers (%)	Fat (%)	Total Carbohydrate (%)	Total Sugars (%)	Dry Matter (%)	Reducing Sugar ($mg \cdot g^{-1}$)	No Reducing Sugar ($mg \cdot g^{-1}$)	Retrogradation	Phosphor (%)	Nitrogen	References
Palmyrah (*Borassus flabellifer* L.)	18.77	81.23	ND	10.36	0.07	0.53	ND	0.34	0.14	88.08	ND	ND	ND	ND	ND	ND	ND	[5]
Canna indica L.	ND	ND	5.91	6.99	0.22	1.75	ND	ND	0.43	ND	ND	93.01	0.12	0.08	ND	ND	ND	[8]
Ñame (*Dioscorea rotundata* P.)	26.78	73.22	ND	8.26	0.48	7.64		0.88	0.28	ND	ND	ND	ND	ND	ND	ND	ND	[9]
Criolla potato clones (*Solanum tuberosum*, Phureja Group)	14.05–49	51–85.95	ND	14.4–21.67	ND	ND	ND	ND	ND	ND	15.06–22.57	19.17–26.42	1.46–6.39	ND	ND	ND	ND	[12]
Inhambu (*Dioscorea trifida* L.)	36.82	47.74	5.92	12.8	0.52	0.43	ND	ND	0.17	ND	ND	ND	ND	ND	ND	ND	ND	[28]
Yucca (*Manihot esculenta*) "Valencia" Variety	38.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	[6]
Mapuey (*Dioscorea trifida*) purple variety	43.33	56.67	4.12	11.49	0.11	0.06	ND	0.0031	0.02	ND	ND	ND	ND	ND	ND	ND	0.009	[19]
Mapuey (*Dioscorea trifida*) white variety	34.72	65.28	4.25	9.05	0.07	0.36	ND	0.0173	0.07	ND	ND	ND	ND	ND	ND	ND	0.06	
Andean Achira Roots (*Canna edulis*)	33.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	[20]
Dioscorea remotiflora	ND	ND	ND	6.29	0.44	0.67	1.2	ND	ND	97.67	ND	ND	ND	ND	ND	0.49	ND	[21]
Dioscorea sparsiflor	ND	ND	ND	7.52	0.73	1.22	0.55	ND	ND	97.46	ND	ND	ND	ND	ND	0.32	ND	
Sweet potato white-skinned variety	32.15	ND	ND	5.46	0.2	4.38	ND	0	2.21	ND	ND	ND	ND	ND	ND	ND	ND	[23]
Sweet potato red-skinned variety	34.16	ND	ND	4.82	0.3	5.56	ND	0	2.28	ND	ND	ND	ND	ND	ND	ND	ND	
Xanthosoma sagitifolium (tannia)	35.34	ND	ND	13.43	0.2	0.56	ND	ND	0.1	ND	0.08	ND	ND	ND	ND	0.07	ND	[25]
Colocasia esculenta (taro)	30.62	ND	ND	14.01	0.31	0.53	ND	ND	0.27	ND	0.04	ND	ND	ND	ND	0.01	ND	
Purple yam (*Dioscorea trifida*)	5.7	ND	5.6	7.8	0.09	ND	0.3	ND	ND	91.8	ND	ND	ND	ND	ND	ND	ND	[27]
Achira (*Canna indica* L.) variety Brazilian	39	ND	ND	9.76	0.53	0.6	0.15	0.86	ND	ND	ND	ND	ND	ND	ND	ND	ND	[38]
Achira (*Canna indica* L.) variety Colombian	40.76	ND	ND	8.35	0.22	0.81	0.05	0.82	ND	ND	ND	ND	ND	ND	ND	ND	ND	[34]
Yucca (*Manihot esculenta*) "Brasileña"variety	37	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	

Table 4. *Cont.*

Starch Source	Amylose (%)	Amylopectin (%)	Ph	Moisture Content (%)	Ash (%)	Crude Protein (%)	Lipids (%)	Total Fibers (%)	Fat (%)	Total Carbohydrate (%)	Total Sugars (%)	Dry Matter (%)	Reducing Sugar ($mg \cdot g^{-1}$)	No Reducing Sugar ($mg \cdot g^{-1}$)	Retrogradation	Phosphor (%)	Nitrogen	References
Makal	23.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
sweet potato	19.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Yucca	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Sagú	22.69	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Ariá (*Goeppertia allouia*)	39	ND	ND	8.45	0.15	2.4	0.39	2.02	ND	ND	ND	ND	ND	ND	58.3	ND	ND	[40]
Anchote (*Coccinia abyssinica*)	ND	ND	4.44	11.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	[55]
Creole Ocurno (*Xanthosoma*)	26.17	ND	ND	10.82	0.09	ND	ND	ND	0.28	ND	0.05	ND	ND	ND	ND	0.09	ND	[25]
sagittifolium (L.) Schott)	26.17	ND	ND	10.82	0.09	ND	ND	ND	0.28	ND	0.05	ND	ND	ND	ND	ND	ND	
Chinese Ocumo (*Colocasia esculenta* L.)	12.69	ND	ND	9.47	0.19	ND	ND	ND	0.33	ND	0.05	ND	ND	ND	ND	0.12	ND	

ND: Not determinate.

8. Environmental Impact

8.1. Sustainability of the Methods

The anchote starch extraction method used in the study is sustainable and based on renewable resources and agricultural waste [55]. Additionally, the extraction process does not use toxic chemicals or generate hazardous waste, making it environmentally friendly. Bioethanol production from anchovy pulp and waste is also a sustainable alternative to the production of biofuels from renewable resources and agricultural waste.

The Ariá starch extraction method has certain advantages in terms of sustainability [40]. Some aspects that support the sustainability of this method include that the extraction process was carried out using only water, reducing the need for potentially environmentally harmful chemical solvents and ensuring low energy consumption, and starch drying was carried out in an oven with air circulation at 40 °C, a relatively low energy compared to more intensive drying methods requiring only the use of simple materials.

The inhambu starch extraction method is based on the principle of insolubility and uses sieving, washing, and purification techniques with absolute alcohol [28]. This simple method does not require toxic chemicals or expensive processing equipment. Additionally, inhambu is an underexplored and abundant starch source, making it a sustainable alternative to conventional starch sources. Using inhambu as a starch source can contribute to crop diversification and promote sustainable agriculture.

The extraction method used to obtain hawthorn yam starch is sustainable and environmentally friendly. The starch is secured using distilled water, and no toxic chemicals or contaminants are used [9]. In addition, the drying process is carried out at a moderate temperature of 60 °C, reducing the energy consumption and minimizing greenhouse gas emissions. The use of hawthorn yam as a raw material for the production of starch is also sustainable, since it is a plant that is abundantly grown in Colombia and does not require large amounts of water or chemical fertilizers for its cultivation.

The dry cassava starch extraction method stands out for its environmental sustainability [24]. Compared to the traditional wet extraction technique, the dry extraction technique does not generate contaminated wastewater, reducing the process's environmental impact. Furthermore, the product obtained by dry pathways can be used to create diapers and paper, and in the textile industry; this amplifies its potential use and reduces the need to import similar products.

The starch extraction method using a sodium metabisulfite solution, applied in renewable sources such as potatoes, corn, and yucca, is considered sustainable [43]. This is due to the use of renewable natural sources, the efficiency in separating the starch from other vegetal components, which reduces waste generation, and the potential recycling of subproducts such as yucca pulp. Furthermore, its compliance with pharmaceutical specifications indicates the method's capacity to produce a quality product that is suitable for pharmaceutical approaches, which promotes sustainability in terms of security and efficiency.

8.2. Environmental Considerations

Environmental sustainability can be ensured in several stages of starch extraction and bioethanol production from anchovy pulp and waste. Firstly, using agricultural waste as raw material to produce biofuels reduces dependence on fossil fuels and the emission of greenhouse gases. Starch extraction does not use toxic chemicals or generate hazardous waste, reducing its environmental impact. Bioethanol production from anchovy pulp and waste is also a sustainable alternative to the production of biofuels from renewable resources and agricultural waste. Overall, this study demonstrates the potential of sustainable agriculture and biofuel production from agricultural waste to contribute to environmental and economic sustainability [57].

Using low-quality potatoes for starch production may have several positive environmental considerations [2]. Firstly, using low-quality potatoes can reduce food waste and decrease the amount of waste sent to landfills; this can reduce the amount of methane and

other greenhouse gases that are released into the atmosphere and decrease the need for landfill space. Second, starch produced from low-quality potatoes may have a lower environmental impact than that obtained from other sources, such as corn or wheat. Potatoes are a renewable and sustainable source of starch, and their production requires fewer resources than other starch sources. Additionally, the process of extracting starch by water-soaking is relatively simple and does not require the use of toxic chemicals or expensive processing equipment. Third, modifying starch to improve its functional properties can have positive implications for the formulation of food products. Using low-quality potatoes for starch production can have several positive environmental considerations, including reducing food waste, producing starch from a renewable and sustainable source, and improving the functional properties of starch for potential health benefits.

Like any industrial process, the yam starch extraction process has environmental implications that must be considered. Environmental considerations include the use of water in the extraction process, the management of waste generated during the process, energy consumption and associated emissions, and the impact on natural resources and biodiversity [13].

Furthermore, a life cycle assessment of the yam starch extraction process can provide valuable information on its environmental impact and help identify areas for improvement. It is essential to consider the balance between starch production and ecological conservation, ensuring that the extraction process is sustainable and respectful of the environment. The enzymatic method of extracting potato starch can be considered a more sustainable and environmentally friendly option than other extraction methods [37]. However, it is essential to keep some environmental considerations in mind when using this method. These include the use of enzymes: although the enzymes used in enzymatic extraction are biodegradable and non-toxic, their production can have a negative environmental impact. The use of water should also be considered, as the enzymatic extraction process requires water to dilute the potato flour and wash the recovered starch. It is essential to minimize water use and ensure that water is correctly treated before being released into the environment. Waste management is another important aspect: although enzymatic extraction may generate less waste than other methods, managing the waste generated during extraction is necessary to minimize its environmental impact. Enzymatic starch extraction methods for potatoes can be considered more sustainable and environmentally friendly than other extraction methods.

9. Conclusions

This exhaustive review of the diverse methods of starch extraction in tubers and rhizomes has led to an in-depth presentation of the strategies used for this process. Traditional methods, which have been the basis of extraction for a long time, were evaluated using innovative mechanical techniques, solvents, and enzymes. Each approach has its own advantages and challenges, highlighting the importance of carefully selecting the method that will fulfil the specific objectives and considering the environmental aspects. A comparison of the different techniques used in starch extraction is essential to determine the most viable method.

The method of wet milling is more straightforward, and involves immersing the tubers in water to separate starch through processes of sedimentation and filtration. The final result is a white starch with a low amount of chemical pollutants. Obtaining starch from low-quality tubers contributes to waste reduction, offering the method significant sustainability; however, this method presents some disadvantages, such as complexities due to some tubers containing mucilage, which complicating the sedimentation of starch granules and reducing their quality. Furthermore, this process could be laborious and requires several stages, implying a significant time investment. The method using a dry pathway is also a simple process involving dry processes, grinding, and sifting the used tubers; these various stages, such as pre-dehydration and pre-grinding, can add to the complexity and increase the cost of the process. Dry extraction effectively releases starch granules from

raw materials such as yucca, Xanthosoma sagittifolium, and Colocasia esculenta. However, we are looking to improve starch extraction with alternative methods, such as solvents and buffers, although these could be more complex and lead to a significant demand for resources. Finally, some methods use enzymes and chemicals for starch extraction; these, combined with traditional and mechanical methods, can improve the extraction yield and starch properties, such as the starch's solubility and swelling capacity, and also reduce the starch's suspension viscosity. However, these techniques are usually more expensive and complex to apply. Also, it is essential to consider that using solvents can require multiple filtration and wash stages to remove impurities, increasing the complexity of the process as well as the resource consumption.

It is essential to highlight the need for an extraction method that can optimize the process, and to look for techniques that could improve the efficiency and yield of different starch extraction methods.

The quality of the extracted starch was also evaluated, evidencing the importance of maintaining high standards to achieve the market demands and guarantee the utility of the final products.

Starch extraction methods mainly focus on using ultrasound and pulsed electric fields to extract the water-soluble, non-starch polysaccharides used in taro peel. This can present us with a new vision and new techniques to further the starch extraction process, which is used in many industries.

In conclusion, this review provides an integral perspective of the methods of extracting starch from tubers and rhizomes, as well as their sustainability and quality. The combination of traditional and modern approaches that were evaluated, with a commitment to sustainable practices, highlights the need for careful consideration when selecting a starch extraction method to guarantee efficiency and ensure environmental responsibility.

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